Experimental Measurement of Motor Variables with Different Drone Propellers

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***Abstract*—This paper presents the design and application of a motor thrust test bench for small unmanned aerial vehicles (UAVs). The system integrates an ACS712ELCTR-30A-T current sensor and a TAL220 load cell with an HX711 amplifier to simultaneously measure electrical input and thrust output. A brushless motor was tested with eight commercially available propellers under step-input conditions, and the resulting data were processed using MATLAB. The results show that propeller performance depends strongly on material stiffness and geometry: fiberglass-reinforced models delivered the highest thrust, while flexible polycarbonate or polypropylene propellers underperformed. The 50:45N propeller achieved the highest thrust without drawing the most current, making it a strong multipurpose candidate, whereas the 51:45R propeller exhibited the highest current consumption without ranking among the top thrust producers, indicating comparatively low efficiency. Low-thrust, low-current propellers such as the 50:30N may be suitable for lightweight platforms prioritizing endurance. The analysis also highlighted differences in dynamic response, with current reaching steady state faster than thrust, and underscored the importance of sensor precision, as the current sensor resolution decreased near low-current operation and the load cell introduced noise and drift. Overall, this study provides a practical basis for UAV propeller selection, emphasizing the combined roles of thrust, current consumption, material properties, and sensor accuracy in guiding design and mission-specific optimization.**

***Index Terms*—thrust test bench, drone, propeller, brushless motor, Arduino**

I. Introduction

Test benches are an engineering tool adopted across various areas to obtain information regarding the performance of a system [1]. This information is often used to design power optimization strategies, economic alternatives, or simply as selection criteria [2]. Today, as shown in [3], test benches can be in conjunction with the paradigm of Industry 4.0, allowing the creation of digital solutions that aim to increase efficiency.

The main objective of test benches for drone motors is to measure the thrust that each motor can generate under different power levels and with various propellers. Through this methodology, it is possible to experiment with different components to understand the behavior of the brushless motor in terms of thrust and power consumption. This model allows for repeated and verifiable measurements that ultimately ensure proper performance.

Conducting a thrust test for drone motors is important because it determines the drone response when in operation. Studying this variable is essential for selecting propellers that enable better efficiency [4]- [5]. At present, few commercial test benches allow for the proposed research, and they tend to have high costs or to use devices that are not easily accessible. Some of the test benches available on the market have also been discontinued or are subject to patents that are not available to the public [6]. It is worth mentioning that the drone-building community is robust and supportive, which has resulted useful for this team. Rudimentary works such as those shown in [7] and [8] provide inexpensive and easy-to-build solutions that have been taken into account during the development of this project. However, the closeness of the community comes at the cost of formality, which renders the acquisition of specifics more difficult when it comes to market drone propellers.

Building on this context, the present article demonstrates that propeller pitch has decisive impact on UAV motor performance, with small variations leading to significant differences in thrust and current consumption. In addition, qualitative observations suggest that stiffness may also influence results. The proposed low-cost test bench provided replicable measurements, offering a practical tool for propeller selection and mission-specific optimization.

A. Background and State of the Art

The implementation of test benches is a practice that has evolved in various industries and fields such as engineering, aviation, automation, and other technical disciplines. In the aerospace engineering domain at the University of Oklahoma, a test bench was designed and implemented to study the performance of propellers with different Reynolds numbers and varying pitches. The tests were iterated several times for 3 days to ensure the repeatability of the experiment. The results obtained by the researchers demonstrated that the Reynolds number does indeed affect the performance of the propeller [9].

In 2010, a group of researchers conducted high-precision tests on propellers for small aerial vehicles. The methodology involved designing 5 test benches to gather information on thrust, torque, and RPM. The results of the investigation revealed that the torque data collected with the test benches was not very accurate [10].

At EIA University, a test bench was constructed to characterize propellers using torque and thrust coefficients. This was achieved by measuring them through a set of calibrated masses and the thrust generated by the engine. Deformation data were obtained using strain gauges in a cell bar [5].

Test benches can also be designed and applied for complex studies. An example of this is their use in rocket propellers that test or simulate aerodynamic conditions of flight for an aircraft [11].

Concerning mechatronics and mechanical engineering, test benches are often used to emulate real-life conditions in a model, as do [12]- [13], which recreate mechanical loads (e.g., on-road conditions) to evaluate motor performance or to measure controlled motor behavior given certain control variables, as in the works [5]- [11]. This paper focuses on the latter, specifically the measurement of thrust and current for a given drone motor with varying propellers. Accordingly, the creation of a thrust test bench for a brushless motor by varying the propellers to find the optimal ones is proposed. For this project, propellers that were available at EIA University were used.

In recent years, several test benches have been developed to characterize thrust and efficiency of UAV propellers, incorporating high-precision configurations and reproducible experimental methodologies. A recent study reported a system capable of measuring directional thrust forces with high accuracy, avoiding reliance on patented and high-cost equipment [14]. Similarly, experimental trials with commercial propellers have analyzed thrust and efficiency using standard sensors in accessible laboratory setups [15]. However, most of these works focus on general performance comparisons and lack a systematic analysis of propeller pitch as a critical variable in the relationship between thrust and electrical consumption. I this context, the present study introduces a novel approach by implementing a low-cost and easily replicable test bench, specifically designed to quantify how small variations in pitch simultaneously affect thrust and electrical efficiency, thus providing solid experimental evidence applicable to the design and optimization of UAV propulsion systems.

B. Types of Test Benches

There are various ways to set up a test bench and it often involves a creative process to obtain measurements of the variables under study. However, two well-known and easy-to-build methods are scale-based test benches and load cell-based test benches. The first method involves fixing the motor to a block with a weight much greater than the force the motor can generate. To ensure that it is static, the blades should also be positioned so that the air mass is directed upward. The weight-motor configuration should be placed on a scale that allows for taring, so the measured value corresponds to the thrust caused by the motor. With this technique, data collection is done manually as in [8].

With the second technique, a load cell is used, which is a sensor that measures the force or weight of an object using the Wheatstone bridge configuration. This sensor provides digital data that can be interpreted on a computer. The methodology for this technique requires more effort, but offers more freedom in the measured variables due to its precision. To set up this technique, a static and rigid vertical structure is necessary. An Arduino and an interface to interpret the information along with sensors to measure variables that may include but are not limited to current, voltage, and deformation, are also required [5]- [7].

II. Methodology

A. Materials

Assessing UAV motor performance requires a reliable thrust test bench. The following components were selected considering availability and cost efficiency:

- Arduino UNO R3
- ACS712ELCTR-30A-T current sensor
- TAL220 load cell
- HX711 amplifier module
- Xing-E 2207 1800kv motor
- Readytosky 30A Electronic Speed Controllers (ESC) with 2A BEC
- CNHL 30C 2200mAh 3S LiPo battery

B. Design

The principal measured variables were thrust (output) and current (input). Propeller specifications, expressed as pitch:length (e.g., 50:30), were obtained from the manufacturer. A detailed CAD model (Fig. 1) was developed in Autodesk Inventor 2023 to define the spatial layout of the components and ensure precise assembly of the test bench.

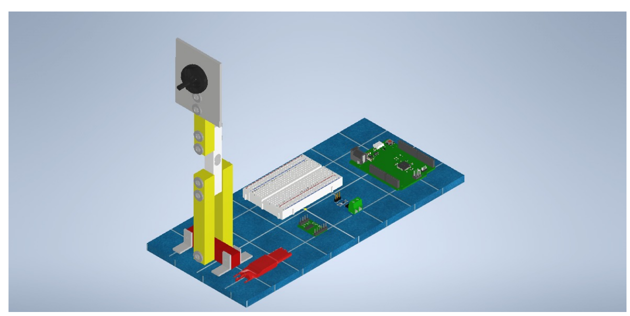

Fig. 1. Motor thrust test bench CAD design.

C. Hardware

Following acquisition of the components, the structural elements were cut in wood and MDF according to datasheet specifications. The motor base (Fig. 2) was produced with tight tolerances to secure the motor and integrate into the load cell assembly.

The assembled bench (Fig. 3) was wired according to manufacturer recommendations. A common ground and 5V supply powered all devices. The Arduino was configured with

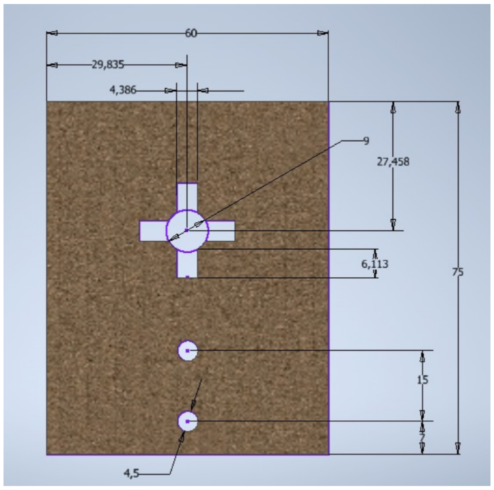

Fig. 2. MDF motor base CAD design. Measurements in mm.

pin A0 for current measurement, pins 2 and 3 for the HX711 clock and data lines, and pin 9 for ESC control.

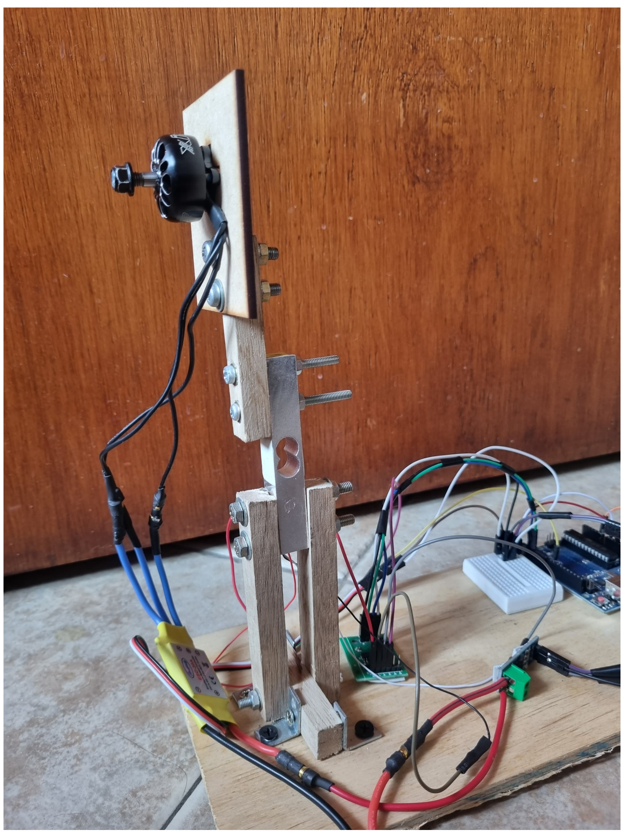

Fig. 3. Assembled motor thrust test bench.

D. Software

The Arduino firmware, written in the Arduino IDE, employed the libraries `EEPROM.h`, `Servo.h`, and `HX711_ADC.h`. It controlled motor actuation, acquired sensor readings, and transmitted results in CSV format via serial communication. A step-input protocol was implemented, with power increments of 4000 ms and shorter shutdown intervals to protect the battery.

A complementary Python script, `ArduinoPostgreSQL.py`, handled serial data storage in a local PostgreSQL database. The output consisted of thrust, current, time, and propeller specifications.

E. Motor Thrust Test Bench

The motor was controlled through a 30A ESC and a 3S LiPo battery, following a pulse protocol with power increments at 4 second intervals, programmed in Arduino and automatically logged into a database via Python, following the procedure for a step test [5]- [7]. The tests were repeated for eight propellers of different pitches and materials, in order to analyze their influence on thrust and electrical efficiency. This procedure enabled the acquisition of replicable and comparable data, ensuring traceability in propeller selection according to thrust, power consumption and material stiffness criteria.

F. Data Collection

For each test, the propeller was mounted and oriented, and the motor was powered through the ESC and LiPo battery. The Arduino automatically executed the programmed sequence, while the Python script recorded the corresponding sensor data. Upon completion, the battery was disconnected and the next propeller prepared.

This procedure was repeated for eight propellers: 50:30N, 50:43A, 50:43N, 50:45N, 50:43E, 50:43T, 51:45R, and 50:45V. Numerical codes denote diameter (inches divided by 10) and pitch (degrees), while letters indicate differences in physical traits such as material or stiffness.

Post-processing and visualization were conducted in MATLAB 2024A (Section III), using line charts to analyze thrust–current relationships and temporal trends.

III. Results and Discussion

After applying the methodology described in Section II, the data were processed and graphed using MATLAB in order to facilitate interpretation and analysis of the results. The discussion is organized into three main parts: thrust analysis, current analysis, and a detailed comparison of the propellers.

A. Thrust analysis

Fig. 4 shows the thrust over time for the eight tested propellers. The 50:45N, 50:45V, and 50:43E propellers achieved the highest maximum thrust values, with results that were very close to one another. In contrast, the lowest performance was obtained with the 50:30N, 50:43A, and 50:43N propellers, which are clearly separated from the others in terms of maximum thrust. These results align with the expectation that propellers with lower pitch typically produce lower thrust.

It is important to note that no quantitative rigidity test was performed; however, it was qualitatively observed that the propellers that bent less during the tests also yielded higher thrust values. As summarized in Table I, the composition of

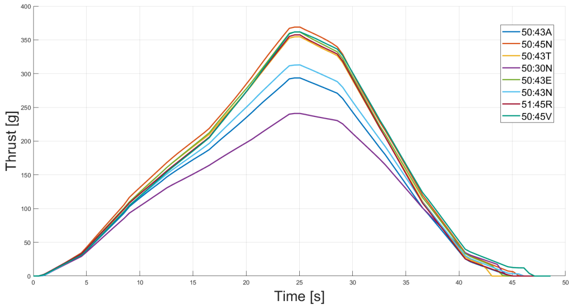

Fig. 4. Thrust versus time for all tested propellers.

the material was an influential factor: the lowest performance propellers were manufactured from easily bendable plastics such as polycarbonate (PC) or polypropylene (PP). The highest thrust values were obtained from fiberglass-reinforced propellers, while the remainder of the tested propellers were made of nylon (PA11). This suggests that stiffness and material composition play a key role in thrust performance.

TABLE I
MAXIMUM AND MEAN THRUST FOR ALL TESTED PROPELLERS.

Propeller	Max Thrust [g]	Mean Thrust [g]
50:45N	368.98	160.49
50:45V	361.87	153.64
50:43E	361.68	159.06
51:45R	357.48	153.64
50:43T	354.67	160.68
50:43N	312.93	137.54
50:43A	293.62	133.63
50:30N	241.00	119.15

B. Current analysis

The current consumption of all propellers over time is shown in Fig. 5. As summarized in Table II, the highest maximum current values were recorded with the 51:45R, 50:43T, and 50:45N propellers, while the lowest corresponded to the 50:30N, 50:43A, and 50:43N propellers. The difference between the lowest and second-lowest maximum currents was greater than 2 A, indicating a clear separation in performance.

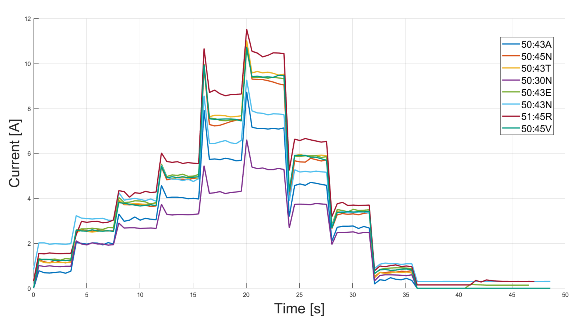

Fig. 5. Current versus time for all tested propellers.

During each step of the test, current spikes occurred during the transitions, as seen in Fig. 5. These spikes were caused by the instantaneous nature of the step inputs applied to the motor. Despite these transients, all propellers exhibited similar behavior, with no noticeable differences in the time required to reach steady state. The sampling time for both current and thrust was 500 ms, and each step lasted 4 seconds. This duration was chosen because the current consistently reached steady state within this time frame. However, as shown in Fig. 4, thrust required more time to fully stabilize, highlighting the inherent complexity of electromechanical systems, where electrical variables often respond faster than their mechanical counterparts.

TABLE II
MAXIMUM AND MEAN CURRENT FOR ALL TESTED PROPELLERS.

Propeller	Max Current [A]	Mean Current [A]
51:45R	11.52	3.82
50:43T	11.02	3.49
50:45N	10.85	3.23
50:45V	10.73	3.23
50:43E	10.65	3.42
50:43N	9.27	3.18
50:43A	8.74	2.58
50:30N	6.61	2.16

The observed behavior is consistent with expectations: more current is needed to accelerate the motor (increasing speed) than to decelerate it. This effect can be attributed to a combination of hysteresis and sensor sensitivity, both of which become evident in the small asymmetries observed during the current transients.

C. Detailed comparison and propeller selection

There is no single criterion that universally determines the optimal choice of propeller. Instead, selection depends on the specific requirements of the application, where factors such as thrust capacity, current consumption, efficiency, and flight conditions must be considered together. The analysis presented in Tables I and II provides useful information on these trade-offs.

Among the tested models, the 50:45N propeller stands out as a potential multipurpose option. It achieved the highest maximum thrust while not being the most demanding in terms of current, making it attractive for applications requiring both strong lifting capacity and reasonable efficiency. In contrast, propellers that generated lower thrust, such as the 50:30N or 50:43A, also exhibited lower current demands, suggesting their suitability for lightweight platforms where endurance and modest performance are prioritized over raw power. However, the 51:45R propeller demonstrated the highest current draw without ranking among the top three in thrust generation, indicating comparatively low efficiency.

Ultimately, propeller selection must balance the intended application of the drone, payload requirements, and desired flight characteristics. It is also important to note that thrust and current analysis alone cannot provide a complete basis for selection. Additional evaluations should be performed, such as durability testing, aerodynamic efficiency measurements, and vibration analysis, to determine the most appropriate propeller for long-term performance and reliability.

D. Sensor Precision and Sensitivity

The accuracy of both thrust and current measurements depends critically on the sensors used and their limitations.

An ACS712ELCTR-30A-T current sensor, which has a sensitivity of approximately $0.066\,\mathrm{V/A}$ was used. This makes it suitable for capturing large current variations, but reduces its ability to resolve small current changes near zero, introducing uncertainty in low-current readings.

For thrust measurement, a TAL220 straight-bar load cell was employed in conjunction with an HX711 amplifier module. The TAL220 has a rated capacity of $10\,\mathrm{kg}$ and uses a Wheatstone bridge configuration to translate mechanical deformation into a millivolt signal. The HX711 conditions and digitizes this signal, but users must account for offset drift, mechanical hysteresis, and noise, especially in inexpensive modules, unless temperature and wiring are well controlled.

Considering these limitations is essential when interpreting the results:

- For small variations in thrust or current (e.g., during steady-state segments), sensor noise and drift may dominate over meaningful signal changes.
- The observed current spikes (see Fig. 5) may partly reflect sensor sensitivity limits, not just the motor behavior.
- Comparative trends, such as identifying which propeller draws more current or generates more thrust, remain valid despite sensor imperfections, but absolute values should be treated with caution.

IV. Conclusions

This study demonstrates the critical influence of propeller selection on the performance and efficiency of unmanned aerial vehicles (UAVs). The results show that propellers such as the 50:45N offer a balanced performance, achieving the highest thrust while not being the most demanding in terms of current. This makes it a potential multipurpose option for applications that require both lifting capacity and endurance. In contrast, low-thrust propellers like the 50:30N and 50:43A also exhibited low current draw, which may be advantageous for lightweight UAVs prioritizing flight time over raw power. Conversely, the 51:45R propeller showed the highest current consumption without ranking among the top performers in thrust, suggesting comparatively low efficiency.

The temporal analysis of current revealed step-like patterns that reflect controlled motor inputs during testing. Current reached steady state within 4 seconds, while thrust required more time to stabilize, highlighting the natural complexity of electromechanical systems where electrical responses are faster than mechanical ones. This is relevant for UAV control strategies, as stability depends on accounting for these coupled dynamics.

Material composition and stiffness also influenced performance: fiberglass-reinforced propellers achieved the highest thrust, while more flexible plastics such as polycarbonate and polypropylene underperformed. This confirms that structural rigidity is closely linked to thrust efficiency.

Sensor precision further affected the interpretation of results. The ACS712 current sensor, with its sensitivity of 0.066 V/A, provided reliable measurements for large currents but introduced uncertainty in low-current regions. The TAL220 load cell with HX711 amplifier enabled thrust measurements up to 10 kg, but offset drift, hysteresis, and noise remain important considerations. These limitations emphasize that while comparative trends (e.g., identifying the most efficient propeller) are valid, absolute values must be treated with caution.

The findings in this work offer practical guidance for matching propellers to mission-specific requirements, from endurance-oriented aerial imaging to high-thrust applications such as racing or heavy payload lifting. They also highlight the importance of considering both material properties and sensor precision when interpreting performance data.

This research highlights that propeller pitch is a decisive factor in UAV propulsion performance. Even small variations in pitch produced significant differences in maximum thrust and current consumption, directly affecting the overall efficiency of the motor. Furthermore, qualitative observations indicated that the stiffer propellers tended to achieve higher thrust compared to the more flexible ones, suggesting that material properties also contribute to performance. This finding is particularly relevant, as it provides replicable experimental evidence that can serve as an objective criterion for propeller selection according to mission-specific requirements, such as prioritizing payload capacity, endurance, or energy efficiency. Thus, the developed test bench not only allowed for controlled comparison of different propeller models but also represents a low-cost and accessible tool for optimizing propulsion configurations in academic and applied research contexts.

A. Future Work and Research Directions

The thrust and current analysis presented in this work has practical implications across UAV applications including emergency response, delivery logistics, precision agriculture, surveillance, and drone racing. High-thrust propellers (e.g., 50:43T) enhance maneuverability and agility, while balanced designs (e.g., 50:45N) extend endurance and payload capacity. These insights support the adaptation of UAV systems to specific operational demands, promoting targeted design optimization.

To further evaluate and expand the functionality of the thrust test bench, the following experiments are proposed:

- **Sweep/Ramp Test:** Continuously vary thrust to observe system response across the full operating range.
- **Endurance Test:** Assess performance and thermal behavior under prolonged operation.

- **Constant Thrust Test (Closed-Loop):** Evaluate control precision in maintaining fixed thrust amid external disturbances.
- **Settling Time Test:** Quantify response time to reach 90% of target thrust after step inputs.
- **Flight Replay Test:** Use recorded flight data to replicate real-world scenarios on the bench.
- **Sinusoidal and Chirp Tests:** Characterize frequency response and system stability under oscillatory and time-varying inputs.

These tests will contribute to a more robust performance characterization and enable further development of UAV propulsion systems for diverse use cases.

V. Supplementary Materials

1) The external library used to read the signal from the HX711 ADC sensor is available in the HX711_ADC GitHub repository using the following URL: https://github.com/olkal/HX711_ADC.
2) The code utilized in this project is available in the MTTB GitHub repository using the following URL: https://github.com/santy-estrada/MTTB.

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